Field Tests of Acoustic Telemetry for a Portable Coastal Observatory

Marinna Martini and Bradford Butman
U.S. Geological Survey, Woods Hole, MA 02543

Jonathan Ware and Dan Frye
Woods Hole Oceanographic Institution, Woods Hole, MA, 02543

***Abstract* — Long-term field tests of a low-cost acoustic telemetry system were carried out at two sites in Massachusetts Bay. At each site, an acoustic Doppler current profiler mounted on a bottom tripod was fitted with an acoustic modem to transmit data to a surface buoy; electronics mounted on the buoy relayed these data to shore via radio modem. The mooring at one site (24 m water depth) was custom-designed for the telemetry application, with a custom designed small buoy, a flexible electro-mechanical buoy to mooring joint using a molded chain connection to the buoy, quick-release electro-mechanical couplings, and dual hydrophones suspended 7 m above the bottom. The surface buoy at the second site (33 m water depth) was a U.S. Coast Guard (USCG) channel buoy fitted with telemetry electronics and clamps to hold the hydrophones. The telemetry was tested in several configurations for a period of about four years. The custom-designed buoy and mooring provided nearly error-free data transmission through the acoustic link under a variety of oceanographic conditions for 261 days at the 24 m site. The electro mechanical joint, cables and couplings required minimal servicing and were very reliable, lasting 862 days deployed before needing repairs. The acoustic communication results from the USCG buoy were poor, apparently due to the hard cobble bottom, noise from the all-steel buoy, and failure of the hydrophone assembly. Access to the USCG buoy at sea required ideal weather.**

I. INTRODUCTION

In 1998, the National Ocean Partnership Program (NOPP) funded the U.S. Geological Survey (USGS), U.S. Coast Guard (USCG), Woods Hole Oceanographic Institution (WHOI), Massachusetts Water Resources Authority (MWRA), and RD Instruments (RDI) to demonstrate a Portable Coastal Observatory as an approach to the coastal observatory challenge (Fig. 1) [1]. This method to obtain oceanographic measurements in real time would provide an alternative to cabled observatories which are expensive and may be difficult to permit. This acoustically linked observatory was designed to be flexible, easy to install and maintain, and inexpensive [1]. A series of field deployments over several years demonstrated the feasibility of several new technologies: a bottom to surface acoustic link; a robust coastal mooring to receive data from separately deployed instrumentation and retransmit the data to shore; a mooring-to-shore communications design for buoys of opportunity such as USCG channel markers, and a web interface and archive for the data. This observatory concept is described in detail in [1].

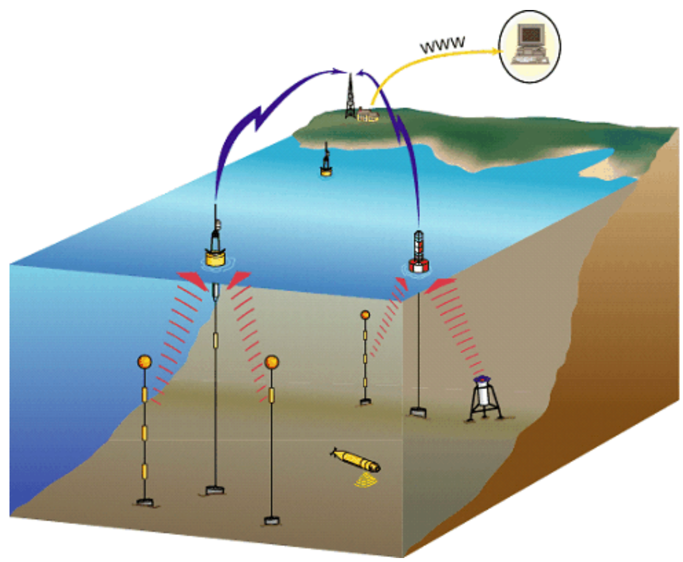

Fig. 1. Conceptual drawing of the Portable Coastal Observatory illustrating the acoustic and RF data links from sea to shore and the final connection to the web.

II. PORTABLE COASTAL OBSERVATORY SYSTEM

The technical goals of this project were to demonstrate the feasability and reliability of: A) low-cost acoustic modems deployed with each instrument, B) small, easy-to-deploy surface buoys and moorings that carry the hydrophones, acoustic receiver and RF link as an acoustic gateway, C) a shore-based receiving station that automatically forwards data received and logs it on a web site [2], and D) a secondary command channel to the surface buoys from the laboratory so that acoustic receivers and RF links can be reprogrammed without requiring a site visit. Since there are numerous buoy-to-shore telemetry options such as RF, cell phone and satellite that are well tested, this paper will focus on the acoustic link and mooring design.

A. Low-Cost Acoustic Modems (Micro-Modems)

The modems used in the transmitting instruments were single board acoustic modems developed at WHOI [1]. The modems were configured to be a robust, low data rate, omnidirectional link and to operate reliably in a wide variety of acoustic conditions and deployed geometries [1]. The modems used a conservative frequency hop shift keying

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14. ABSTRACT

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(FHFSK) coding and modulation scheme specifically designed for shallow water operation. This scheme sacrificed speed for more robust performance in horizontal, shallow conditions. During operation, the modem parsed serial output from instrumentation into packets for acoustic transmission to the gateway on the buoy [3]. For this project, the instrumentation was an RDI acoustic Doppler current profiler (ADCP) which output a shortened data string for telemetry while storing all of the data to internal memory. The acoustic modem remained in a sleep mode to save power until RS232 data from the instrument was detected. The modem was self-contained with its own battery and required nothing from the instrument to which it was cabled except data via the instrument's serial port. Swapping between ADCPs required no software or hardware changes to the modem or the ADCP. Adapting other instruments for acoustic telemetry only required changing parsing software in the modem.

B. Custom-Designed Surface Mooring

A new robust surface mooring design (Fig. 2) was tested over several years as part of this project [4]. The mooring design incorporated elements from deep-water telemetering moorings into a small, lightweight, easily-deployed design suitable for shallow coastal environments. The surface buoy was small and compact (0.5 m by 0.9 m dia with 180 kg of buoyancy) to enable deployment and recovery from small vessels. The connection between the buoy and the rest of the mooring is typically a troublesome failure point in moorings where electrical signals must pass from the mooring to the buoy. In this design, a six-conductor coil cord was wrapped around a urethane potted chain which held the load. This joint bore all the bending stresses between the mooring line and the buoy. The couplings between the coil cord and the electro-mechanical cable consisted of a steel plug and receptacle with a locking pin (Fig. 2 "B"). The plug was hollow and protected the connection between two RMG inline electrical cable connectors inside the mechanical joint that transmits the load. In the case of this mooring, the electrical signals originated from the two mid-water hydrophones. To aid in deployment and recovery, chinese fingers were attached to the electro-mechanical cable as pickup points. A light-weight dor-moor anchor (114 kg) was chosen so that the mooring would walk rather than sink in stormy weather if design loads were exceeded. The mooring was designed to be easy to hook into and move if it needed to be reset.

C. Using an Existing USCG Channel Buoy

An existing USCG navigational buoy was converted to an acoustic gateway by attaching the gateway electronics and hydrophone to the buoy while it was in service. The USCG allowed free access, but required that the buoy's buoyancy and stability not be compromised and the buoy not be physically modified. A clamp was designed to secure a tube to the side of the buoy through which the transducer could be inserted (Fig. 7). The tube enabled the transducer to be removed without changing the entire clamp assembly. Electronics pressure cases were attached to the buoy's superstructure.

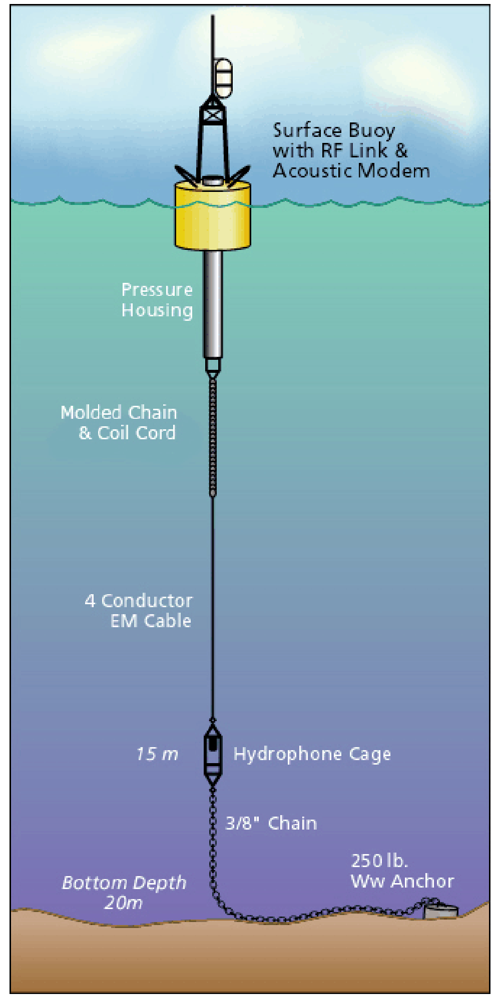

Fig. 2. Mooring schematic for the Gateway mooring

D. Acoustic Gateway Buoy Electronics

The electronics installed consisted of: a utility acoustic modem (UAM) which receives and decodes acoustic packets, a Freewave RF modem to send data to shore, a UHF radio receiver that allows remote start and shutdown (the back channel) and batteries. The UAM functioned as the system controller receiving acoustic data and managing the scheduling of the other radios. Data received via RS232 from an instrument by a Micro-Modem was broken into packets that were transmitted acoustically to the UAM on the surface buoy where the packets were decoded and reassembled into the original ASCII data sent from the instrument.

Remote control of the gateways was accomplished with a UHF radio receiver and DTMF (dual tone multi frequency) decoder. A handheld radio (450-470 MHz) could transmit short sequences of DTMF codes to control power to the different sub-systems on the gateway buoy such as power cycle the system or put it into a low power sleep mode. Remote control of the gateways was possible from the computer located at the shore receive site via a fixed 5 Watt UHF transmitter. Remote users could log on to the computer and issue commands that would send codes to gateway buoys via the UHF transmitter. During periods when data was not being transmitted over the acoustic link, gateway buoys could be remotely placed in low power sleep mode and then turned on when a new acoustic modem was deployed.

III. PORTABLE OBSERVATORY FIELD TESTS

Two subsurface moorings and bottom tripods were being maintained by the USGS at sites east of Boston and at Scituate (Fig. 3) as part of a long-term study in cooperation with the MWRA [5] to predict the fate of contaminants introduced to Massachusetts coastal waters. Using the Portable Coastal Observatory, these sites were converted to telemetering installations which transmitted ADCP data from bottom tripods to the USGS offices in Woods Hole, MA. Acoustic gateways were installed on surface moorings, and transmitters were installed on bottom instrumentation. At Scituate, a dedicated gateway buoy was deployed, and at Boston, a gateway was added to the existing USCG channel buoy "B" 10 miles east of Boston, MA. The USCG allowed free access to a communications tower at Marshfield, MA, to be used as the shore receive station (at an elevation of about 60 m). RDI loaned the USGS two 300 kHz Workhorse ADCPs which could be swapped out or moved around to test the robustness of the links at the Boston and Scituate sites without disrupting the regular long-term data collection program.

The design and construction of the electronics, mooring and buoy mounts, and access to a USCG tower to install the receive station took approximately eighteen months. The start-up cost of the equipment, not including salaries for design, installation, programming and testing, was about $50,000. Life cycle costs were minimal, since archival resources and data processing technology already existed at WHOI and USGS. Life cycle costs were mainly personnel and ship time for field work and computer maintenance.

Telemetry equipment was maintained in the field from early 1999 through February of 2004 (Fig. 4). Deployments, recoveries and repairs of equipment were performed from the USCG buoy tender *Marcus Hanna* during scheduled research cruises for the USGS Massachusetts Bay Long-Term Station and from the fishing vessel *Christopher Andrew* as needed. The USCG was unable to provide ship time during the winter and spring 2002 due to duties associated with events on September 11, 2001, and scheduled maintenance and deployments of the telemetry equipment were delayed during this time.

A. The Small Gateway Buoy at the Scituate Site

The Scituate gateway mooring was first placed in service in October 1999 (Fig. 5). Tripods were typically deployed 140 m from the gateway buoy. The first real transmissions were successfully received in March 2000. A succession of deployments up to October 2001 employed different methods to improve the link. Initially the transmitting modem at the ADCP was a UAM, but this was changed to a Micro-Modem in the summer of 2000 when the Micro-Modem design was completed. The greatest improvement came from changing the frequency hop scheme in June 2001. The frequency hops were spaced out in time to maximize the clearing time of noise and reverberation due to shallow water acoustics.

After October 2001, data transmissions through the link were nearly error free. During the winter of 2002, data were received with low error rates for 199 days at a distance of 0.43 km from the tripod to the gateway buoy. During the winter of 2003 this distance was extended to 0.5 km. Gaps in data were due to human error in setting up instruments, gaps in deployment or the tipping of a tripod which put the transducer into the bottom. Tripod #699 was deployed with the ADCP's RS232 output disabled. Tripod #710 was deployed with an acoustic transmitter, but the gateway buoy had to be recovered for repair and refurbishment. Tripod #719 was tipped over by a significant winter storm. Though tripods were deployed at depths of 25 m, winter storms and wave noise did not appear to affect acoustic data transmission quality as long as the tripod remained upright. The low power Micro-Modems usually lasted 180 days at an hourly transmission rate. Tripods were typically deployed for 120 days.

The ADCPs transmitting the data over the acoustic link were mounted on small bottom tripods (Fig. 6). The tripod recovery floats could shadow the acoustic signal if the tripod's orientation positioned the floats between the transmitter on the tripod and the buoy. This appeared to be true even when the transducer was deployed high on the tripod's structure. In one case, a tripod which had been transmitting with few errors,

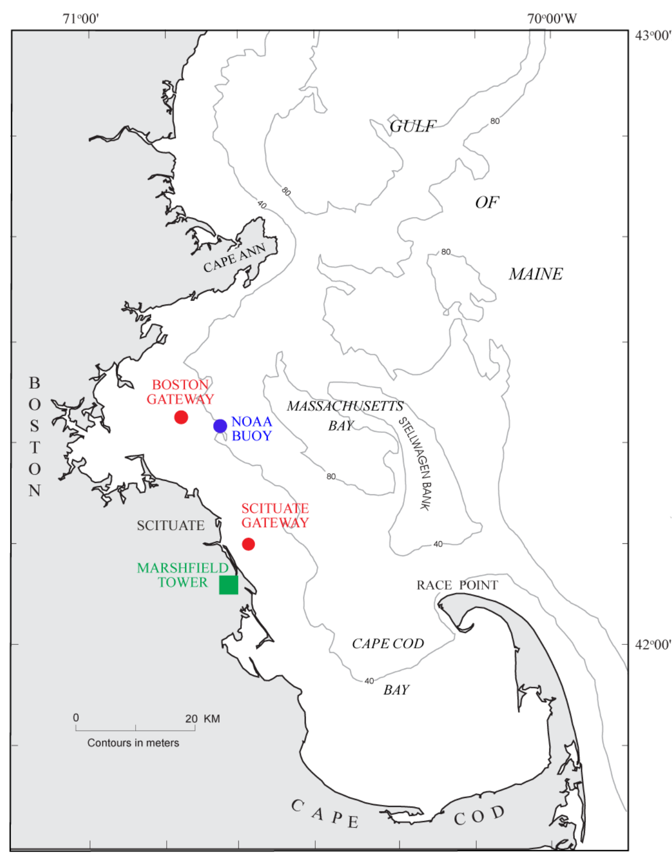

Fig. 3. Map showing location of telemetry sites, shore station and nearest NOAA buoy.

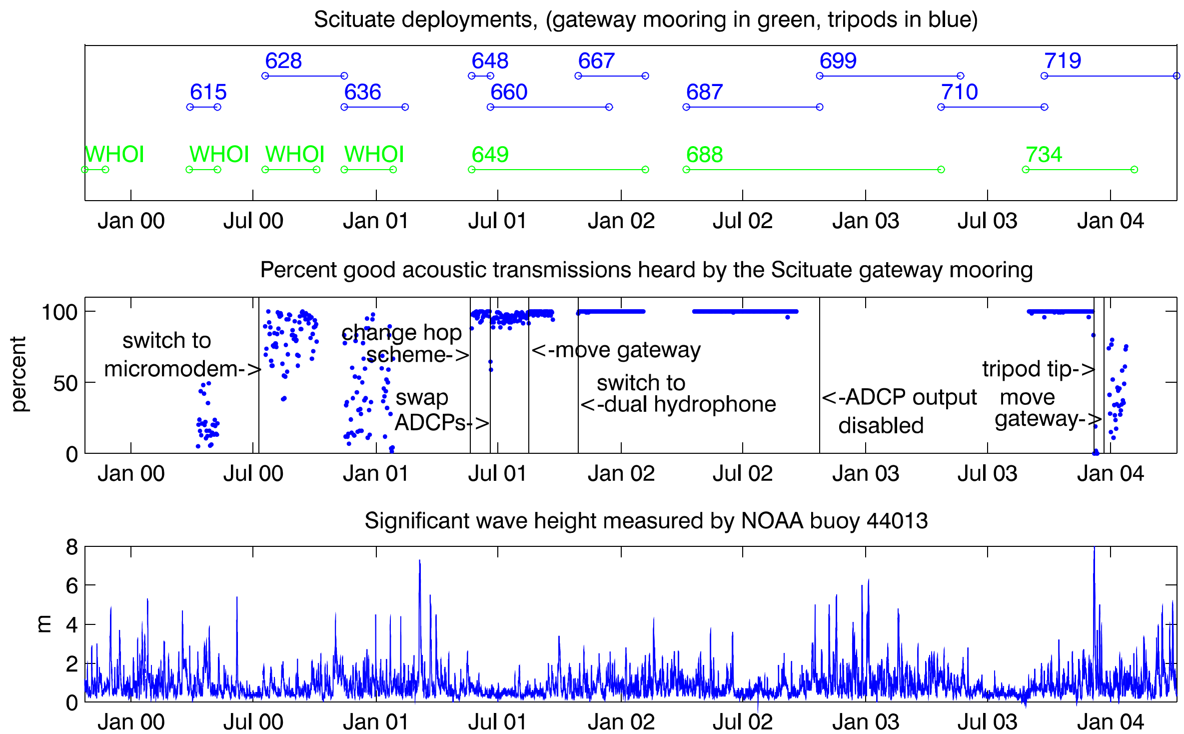

Fig. 4. Time line of gateway mooring and tripod deployments for the Scituate site. Each USGS deployment is labeled with an identifying USGS mooring or tripod number (A). Plot of success rate of transmissions (percentage of total transmissions heard by the gateway) and significant events (B). Plot of significant wave height at NOAA buoy #44013 (C).

was recovered and redeployed to swap ADCPs. The redeployed position, while equally distant from the gateway buoy, caused degradation in the received signal. A change of buoy position from northeast to southwest of the tripod at the same distance restored the acoustic reception to near error free (160 bps coded and 80 bps net data rates).

The gateway mooring design was used in multiple deployments from October 4, 1999 through April 23, 2003 before needing refurbishment. Over this period, the dual hydrophone array (15-22 kHz band) was installed and batteries changed. During the April 2003 recovery of buoy #688, the chinese finger pickup points on the electro-mechanical cable were missing, and the cable had to be wound on a small diameter capstan in order to recover the mooring. The electro-mechanical cable was bent too much and needed to be replaced. The rest of the mooring components, including the coil cord buoy to mooring joint were serviceable after being deployed for 862 days. The mooring, with a new electro-mechanical cable and chinese fingers, was redeployed in the fall of 2003 for 162 days.

The storm in December 2003 that tipped over the tripod, also moved the gateway mooring 3.4 km south of its original position. The mooring was repositioned to attempt a series of range tests, but transmissions from Micro-Modem on the tripod were much less effective with the tripod on its side and the transmitter close to the sea bed. Only few transmissions were received, making the tests inconclusive. During the last move, excessive buildup of ice on the buoy had damaged the radio antennae. The mooring was recovered in February 2004 and and the tripod was finally rescued by divers in April 2004. At this time, the MWRA and USGS discontinued measurements at the Scituate site, ending the deployment of telemetered equipment.

B. USCG Channel Buoy at the Boston Site

To transmit data from the Boston site, the gateway was installed on an existing USCG buoy. The receive transducer consisted of a molded hydrophone array extending 3 m down the side of the buoy, terminating above the buoy's chain bridle. Electronics cases were attached to the buoy's superstructure, on either side of the bell just above the solar panels. The RF antenna was attached to the top of the buoy tower, at an elevation of about 6 m above sea level.

The buoy could only be accessed during the calmest weather. The buoy installation endured storms with significant wave heights as high as 4.2 m as reported by a nearby NOAA buoy. The clamp mount remained in place on the buoy during the entire experiment, interrupted only when the buoy was serviced by the USCG. The molded transducer was removed and reinstalled separately (Fig. 7), as were the pressure cases strapped inside the buoy tower structure.

The Boston gateway was deployed with two different buoy-to-shore transmission technologies. From July 19, 2000 to November 21, 2000, and for a few days in September 2001, transmission of data to shore relied on Freewave RF modems. Some data were received at the shore station, but not in enough quantity and with enough reliability to learn about the quality of the acoustic link because the distance to the receive station at Marshfield was at the maximum of the RF modem’s range. On August 20, 2002, the transmitter in the gateway

Fig. 5. Deployment of the custom-designed surface buoy at the Scituate site. Buoy is 0.5 m high and 0.9 m in dia. The potted cable is visible at the bottom.

was replaced with an Iridium satellite modem which revealed that data packets were being received reliably from the gateway, but the acoustic data were unreliable. The Iridium system failed on October 19, 2002 when the Iridium transmitter shorted and damaged the power control board for the entire system.

Acoustic transmission tests were performed at the Boston site. In September, 2002, hand-deployed transducers were used from the boat to verify signals received from the tripod. Acoustic signals were received reliably when both the receive and transmit transducers were at approximately the same depth. Transmissions from the bottom to the surface, however, were usually degraded by errors. In August 2003, the molded hydrophone on the buoy was found to be damaged, and it was replaced by two test hydrophones. The receiving UAM on the buoy was able to decode signals error free transmitted from a range of up to 350 m. There was significant noise generated by the buoy, including impulse noises from waves hitting the steel hull and metal parts

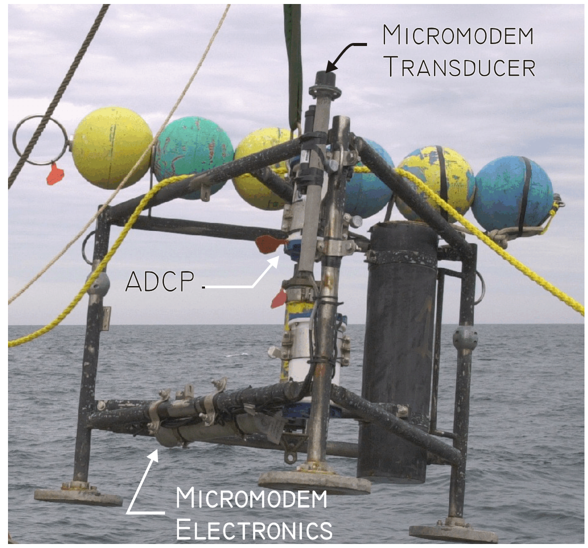

Fig. 6. Deployment of a typical bottom tripod. The acoustic transmit electronics, transducer, ADCP are labelled. Also visible are the ADCP external battery pack, recovery floats, rope cannister and acoustic release. Frame is about 2 m high and 2.5 m wide.

clanging. Digital audio tape recordings of the test hydrophone received signals revealed strong multipath arrivals at the buoy. There was enough signal strength to decode correctly out to 1 km, however the FSK technique being used could only tolerate 40 msec of signal spreading, and spreading was observed up to 250 msec at 1 km.

VI. CONCLUSION

At Scituate, using the small custom-designed mooring, a consistent flow of error free data transmissions was maintained for three deployment periods totaling 239 days and greater than 90% good packets were received during a fourth deployment period of 61 days (Fig. 4). Attaching acoustic modem equipment to the ADCPs and maintenance of the gateway buoy were routine, interrupted only by the usual problems of field work: human error, funding levels, bugs in processing code and weather events. By the end of the experiment, Micro-Modems were being routinely added by USGS to the monitoring deployments during science cruises on USCG buoy tenders. The back-channel communications system worked well.

The custom-designed gateway mooring survived all weather conditions. As intended during severe weather, the mooring drifted, but did not sink. Only the electro-mechanical cable needed replacement over a period of 2.8 years, after it was abused during recovery. The electro-mechanical, in-line couplings survived the entire time without failure and were easy to service. The electro-mechanical connection under the buoy, which was expected to be the weakest link due to wave action, never failed.

At Boston it was difficult to maintain data throughput. The link between the gateway buoy and the shore receiver was too distant for a Freewave modem to work reliably. These range limitations made Iridium satellite transmission more

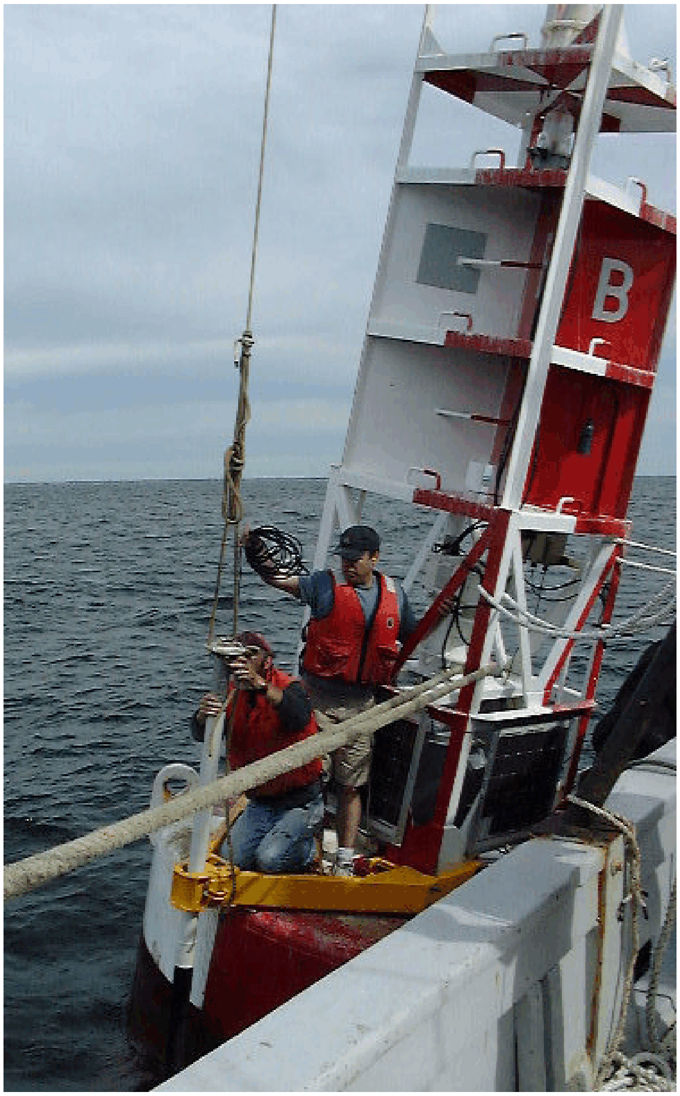

Fig. 7. USCG buoy at the Boston site. Engineers remove the molded hydrophone tube (white) from the special buoy mount clamp (yellow). Servicing required very calm conditions.

attractive. By the time satellite communications were established, the molded hydrophone array was too damaged to receive acoustic transmissions.

Tests revealed that the acoustics of the hard cobble bottom at the Boston site plus the typical sounds generated by the steel USCG buoy hull made for a very noisy acoustic environment. While the USGS was allowed free access to the B-buoy by the USCG, weather usually limited access by the small fishing vessel *Christopher Andrew*. Access to the buoy was easier with the USCG buoy tender *Marcus Hanna*, but the buoy tender was typically only available to the USGS three times a year.

The equipment on the USCG buoy at Boston did not survive as well as the Scituate mooring. It is unknown how the molded transducer array was damaged, however the clamp and electronics cases remained intact and secure on the buoy throughout all weather conditions.

Acoustic modem capabilities have evolved since this project was completed. Micro-Modems are now capable of transmission and receive rates up to 5000 bps. UAMs are obsolete, and have been replaced by Micro-Modems with daughter boards that are capable of decoding high rate PSK transmissions. This technology is being actively used for autonomous underwater vehicle communications and deepwater mooring telemetry.

Based on the tests reported here, the concept of a Portable Coastal Observatory has been shown to be reliable, easy to maintain and inexpensive. Acoustic modems are a viable strategy to obtain reliable real-time observations from remote instruments, but their use can be limited by the horizontal range that can be achieved using a single gateway buoy. It is anticipated that improvements in acoustic modem technology will increase this range substantially, overcoming the challenges of shallow water acoustics and making the Portable Observatory concept more valuable in the future.

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